INDUCED SEISMICITY AND THE O&G INDUSTRY

This presentation represents the collective thoughts of subject matter experts drawn from AXPC member companies and other Oil and Gas Industry companies. The subject matter experts include geologists, geophysicists, hydrologists, and regulatory specialists. This presentation does not represent the views of any specific trade association or company.

KCC/KGS/KDHE Induced Seismicity State Task Force Meeting
Wichita, KS
April 16, 2013

Purpose & Outline

- Overview of induced seismicity
- Propose a framework & workflow for:
  - Screening and assessing
  - Monitoring
  - Mitigating

  Managing Induced Seismicity
- And possible tools to use

Practical and useful for operators and regulators

Induced Seismicity

- Seismicity with spatial and temporal correlation with human activities raises ***the possibility*** of it being induced
- Need to evaluate:
  - Seismicity
  - Geological and geophysical data – esp. faults
  - Geomechanics
  - Hydrologic/reservoir data
  - Operational data

Bearing in Mind . . .

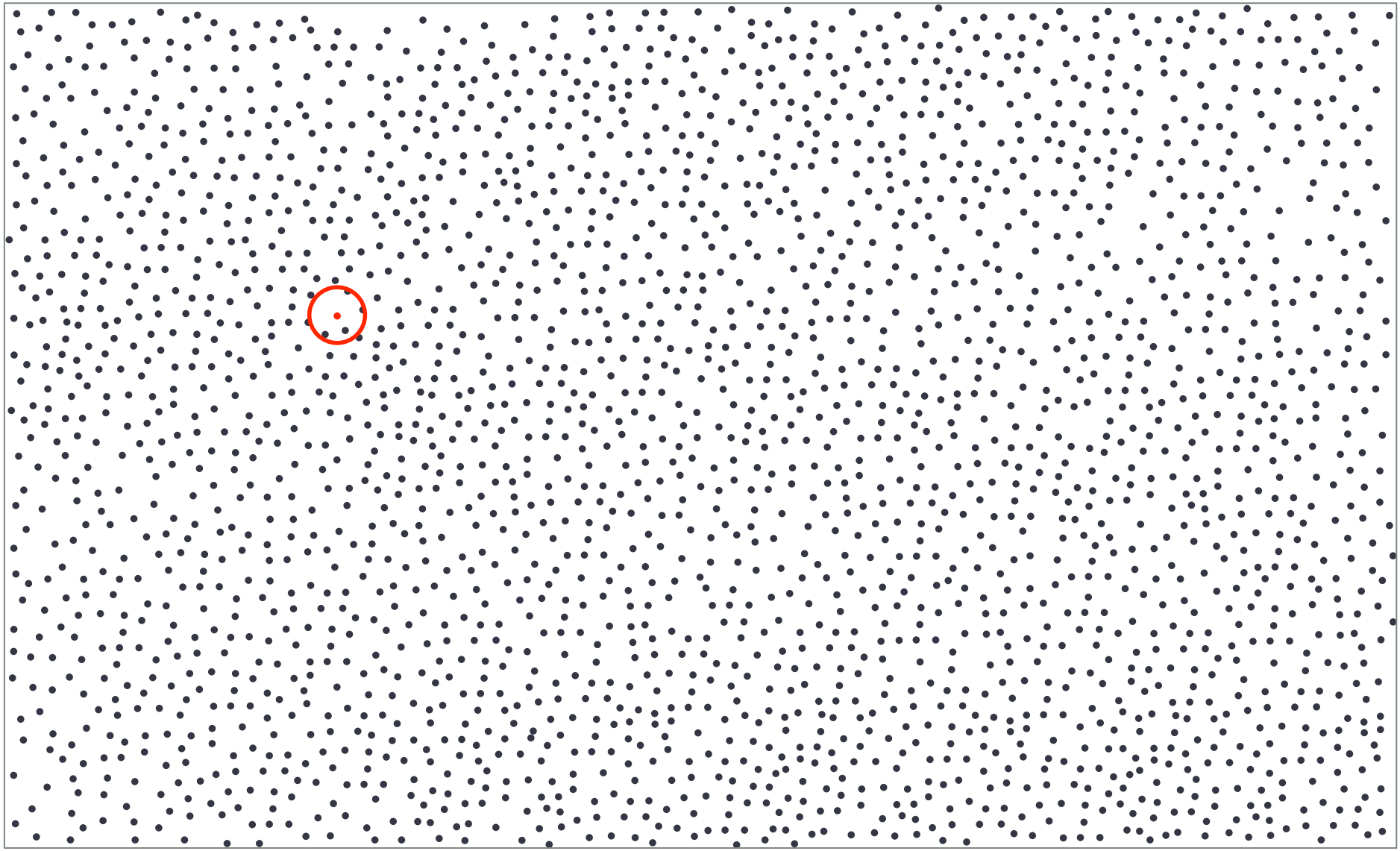
- Earthquakes are unpredictable – even if induced
- Faults are often unseen, unexpected
- Earthquake locations are uncertain - especially depth
- Timing can be geologic in frequency
- Statistics are fine, but outliers with consequences exist
- Absence of seismicity usually means absence of sensors

Induced Seismicity – Oil and Gas

- **Production and EOR (CO_2 & Waterfloods)**
  - Rare cases – water floods and production associated subsidence
  - In-situ stress balanced by withdrawal & injection
- **Hydraulic fracturing**
  - Very rare - near basement structure and/or critically stressed fault
  - Inherent microseismic events, very rarely felt at surface
- **Fluid Disposal** (UIC Class II)
  - Regulated by Federal/State Underground Injection Control Program
  - Rare – less than a dozen of over 30,000 UIC Class II disposal wells
  - Disposal near basement structure and/or a critically stressed fault

Induced seismicity can be managed with operations monitoring and modulation of injection pressures and rates

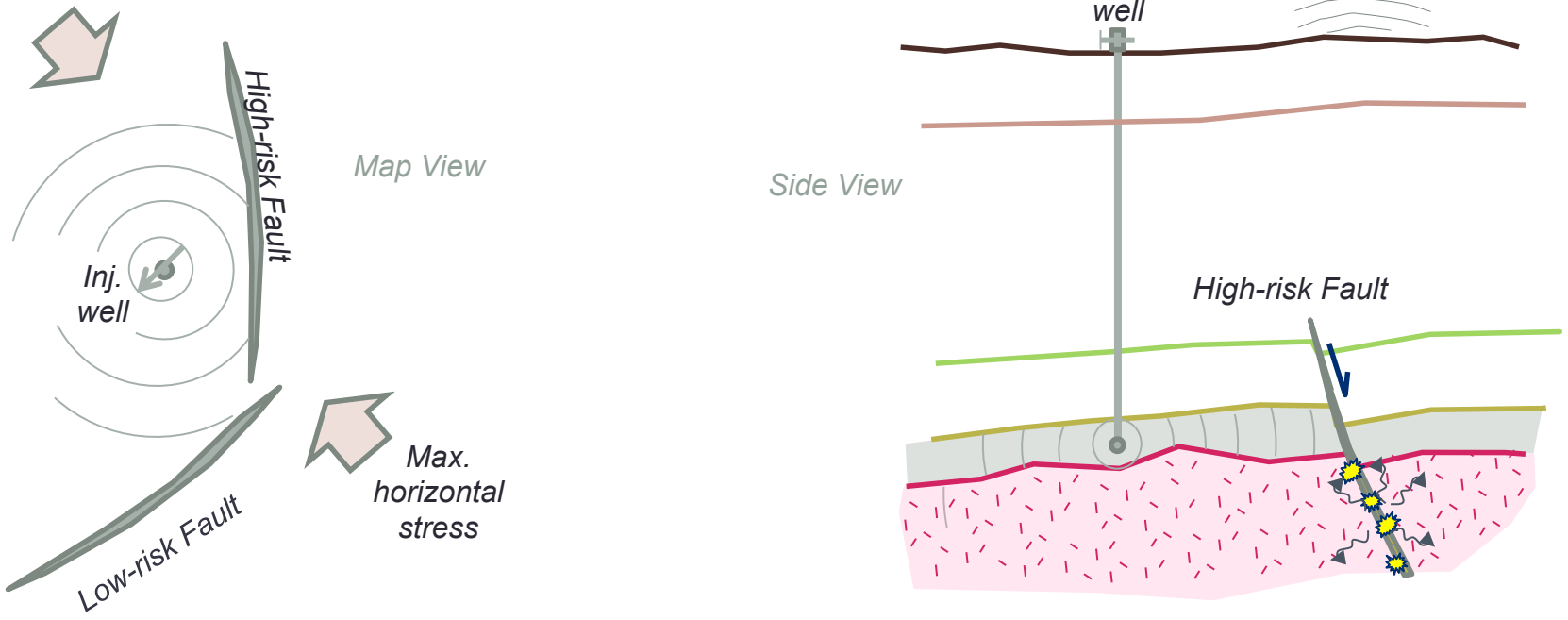
Induced Seismicity – How Rare?



~1 dozen in >30,000 (or 1:2500)

Induced Seismicity – Fluid Injection

- Fluid injection raises pore pressure & stress in subsurface
- Increased pressure reaches a nearby critically stressed fault with a high-risk orientation
- Fault reacts: brittle deformation, especially in basement rock, radiates seismic waves
- Ground motion may result at surface



Schematic example

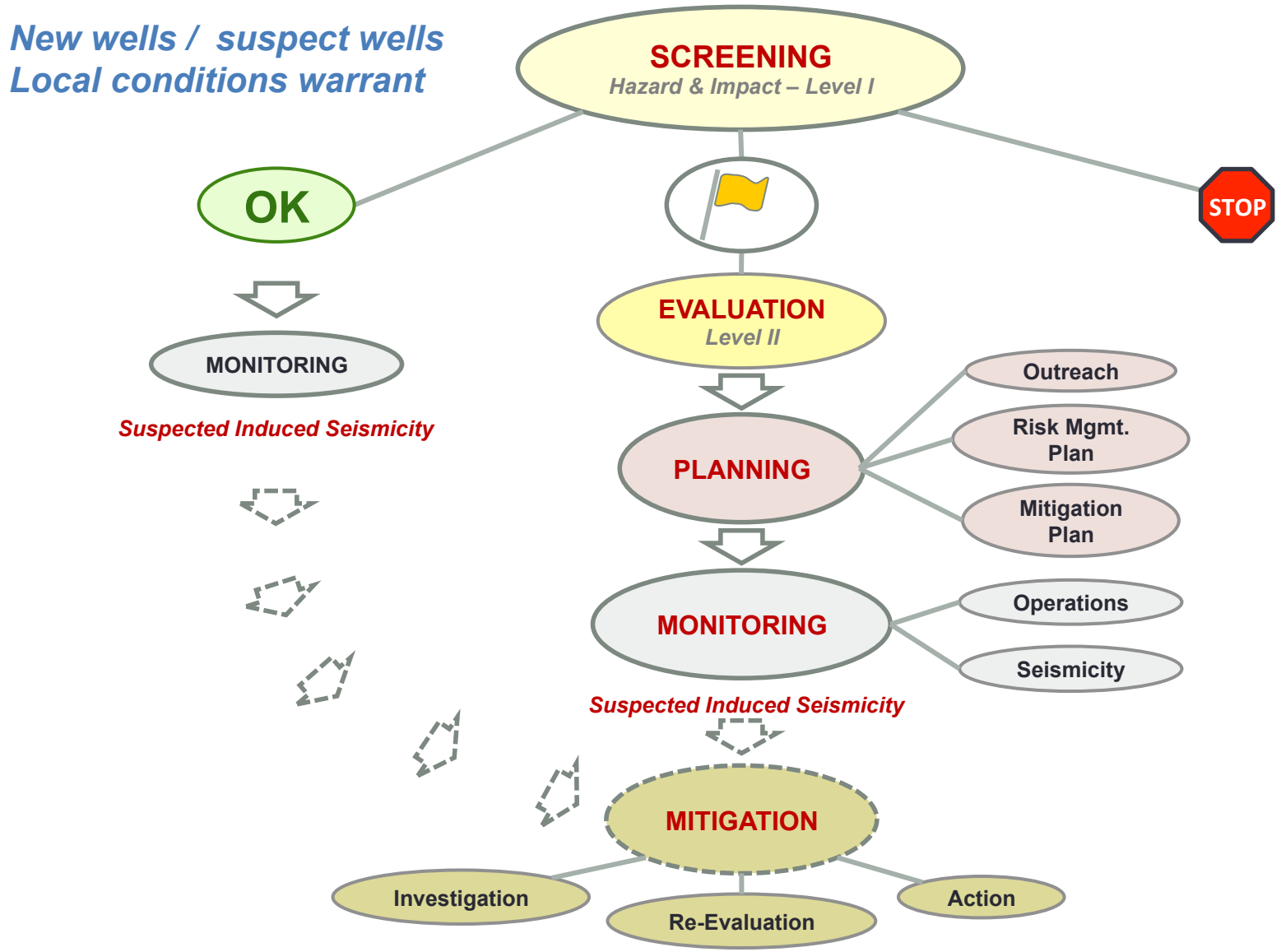
Framework for Managing Induced Seismicity

Highlights:

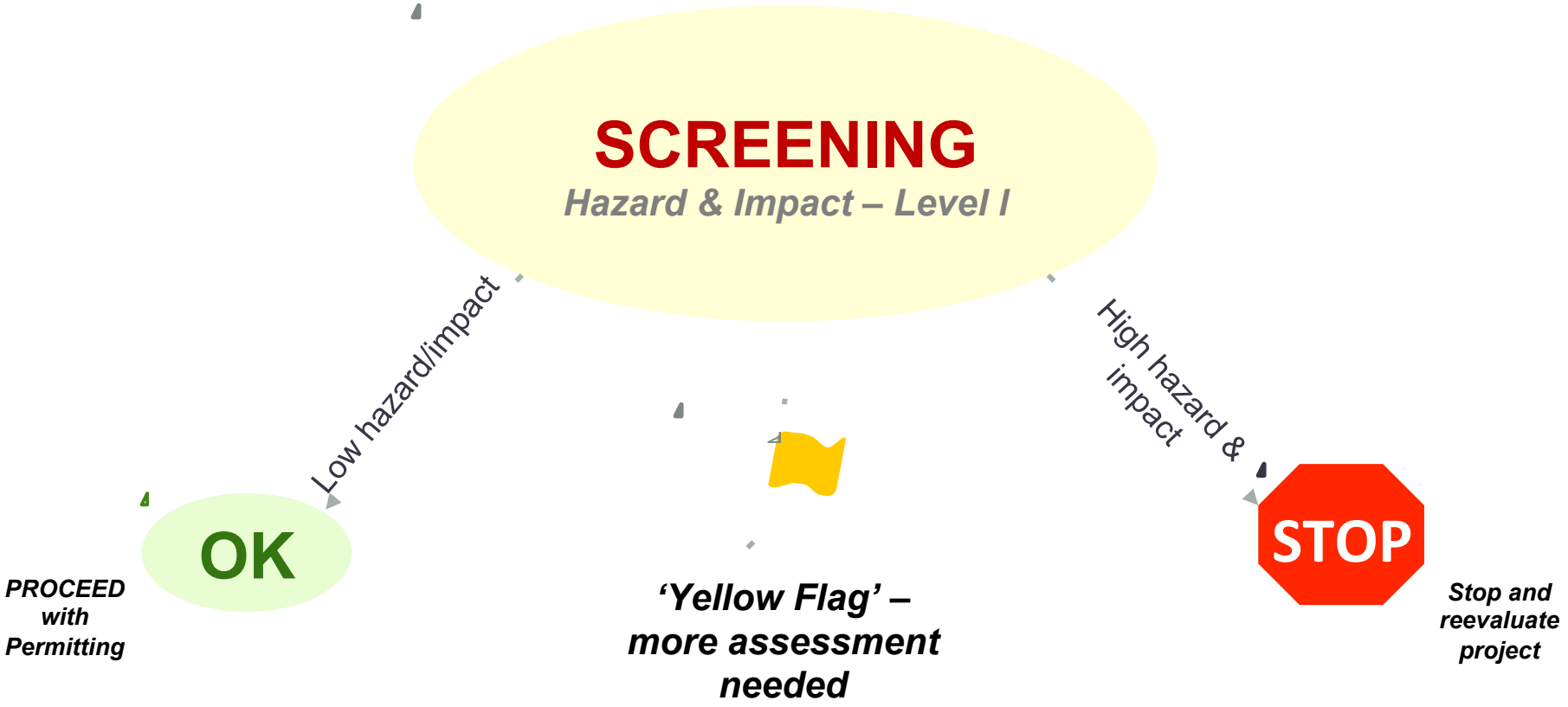
- Proactive approach addressing public and regulatory concerns
- Process for siting new disposal wells, or assessing suspect wells
- Scalable process for varying local conditions including: geology, operations, demographics
- Dynamic – evolves as conditions change
- Plan for mitigation only if/when potentially induced seismicity occurs
- Toolboxes offered to aid in assessment and management

Most disposal wells have no seismicity

Framework for Managing Induced Seismicity



Framework for Managing Induced Seismicity



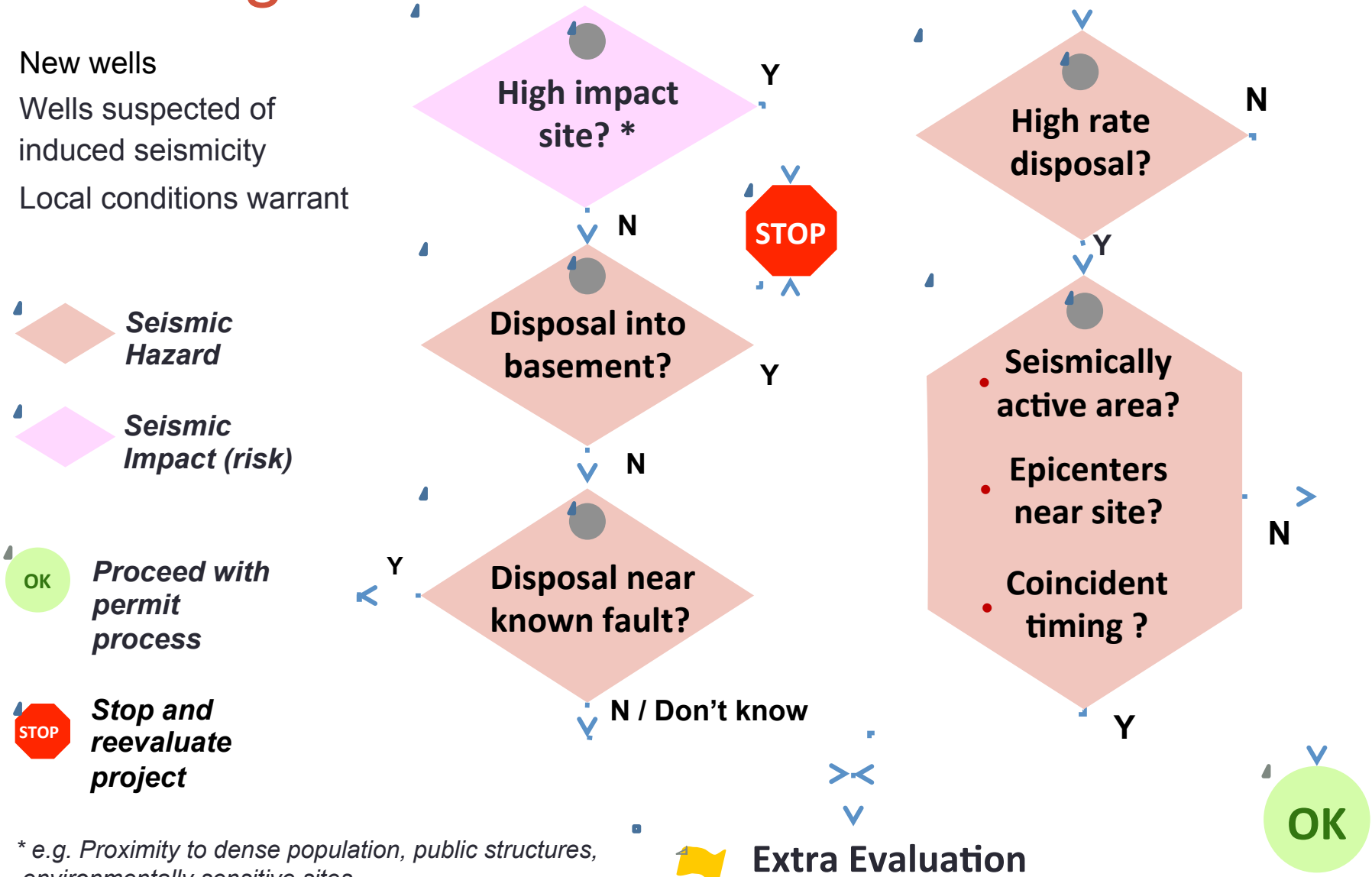
C R I T E R I A

Hazard – The possibility of seismic events and ground motion occurring

Impact – The effect on local population, property, or environment, including distress, damage, or loss (a.k.a. '**Risk**')

Screening – Level I

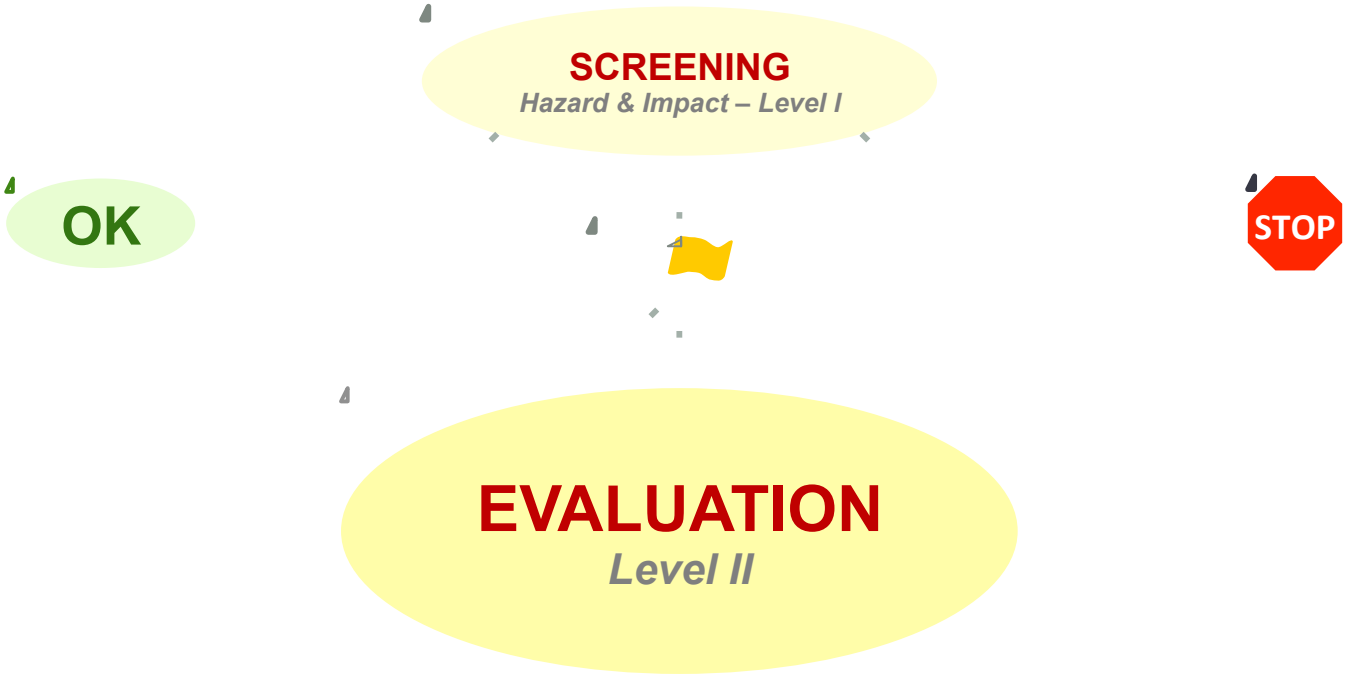
- New wells
- Wells suspected of induced seismicity
- Local conditions warrant



** e.g. Proximity to dense population, public structures, environmentally sensitive sites*

Test criteria modified from Davis & Frohlich 1993

Framework for Managing Induced Seismicity



Some hazard/impact . . .

Evaluation - Level II

Taking a closer look at . . .

Hazard:
- Seismicity
- Geology, geomechanics
- Hydrology / reservoir
- Operations

Impact:
- Human environment
- Natural environment

Evaluation Level II
Scalable Technical Considerations

Hazard
1. Local seismicity – location, depth
2. Local geologic stress and faults
3. Geomechanical modeling
4. Reservoir characteristics
5. Seals and boundaries, separation from basement
6. Pore pressure and fracture gradient
7. Ground conditions and expected seismic motion
8. Planned disposal volumes, rates, and pressures

Impact
1. Susceptibility of population, infrastructure, environment
2. Shake maps and damage models
3. Operator and stakeholder losses and liabilities
4. Probabilistic analyses of hazard and impact

Evaluation – Hazard Evaluation Toolbox

Item	Data, Resources and Tools
Key geologic horizons and features	Data from existing wells, reflection/refraction seismic data, and gravity/magnetic data. Fault presence assessment from mapped horizons and coherency 'ant tracking', proximity to basement from State and USGS maps
Regional stress assessment	World stress map, Stress literature, physical measurement, stress estimates from seismic and/ or nearby well logs. Model effect on the reservoir and surrounding rocks from stress changes associated with fluid injection.
Surface features	USGS geological maps, published reports.
Reservoir characterization	Rock type, facies, age, matrix composition, porosity types, depth, thickness, and petrophysical properties. Lateral extent and continuity, proximity to outcrop, proximity to basement, lateral barriers and conduits, compartments, bounding layers and intervening formations to basement, sealing rocks in system.
Reservoir & rock properties	Permeability, porosity, natural fracture porosity, storativity. Mechanical properties: fracture gradient, closure pressure (ISIP), Young's Modulus, Poisson's Ratio, cohesion, coefficient of friction, pore pressure, lithostatic pressure, hydrostatic pressure, horizontal stress magnitudes and azimuth.
Disposal conditions	Initial saturation, salinity, pore pressure, static fluid level/BHP Fluid injection rates, pressures, cumulative volumes
Local seismic events	Academic (e.g. IRIS), State, and industry surveys. If not available then regional or local dedicated network of seismometers and ground motion sensors. Establish magnitude, frequency of occurrence, and ground motion relationships.
Ground response	Expected peak velocities, acceleration, and spectral frequency. Refer to local civil engineering codes. Models from USGS, state agencies and academia, USGS Shakemaps.
Ground conditions	Consolidation, saturation, composition, potential for reacting to seismic event.

** Toolbox contains various scalable tools user can select to fit for purpose*

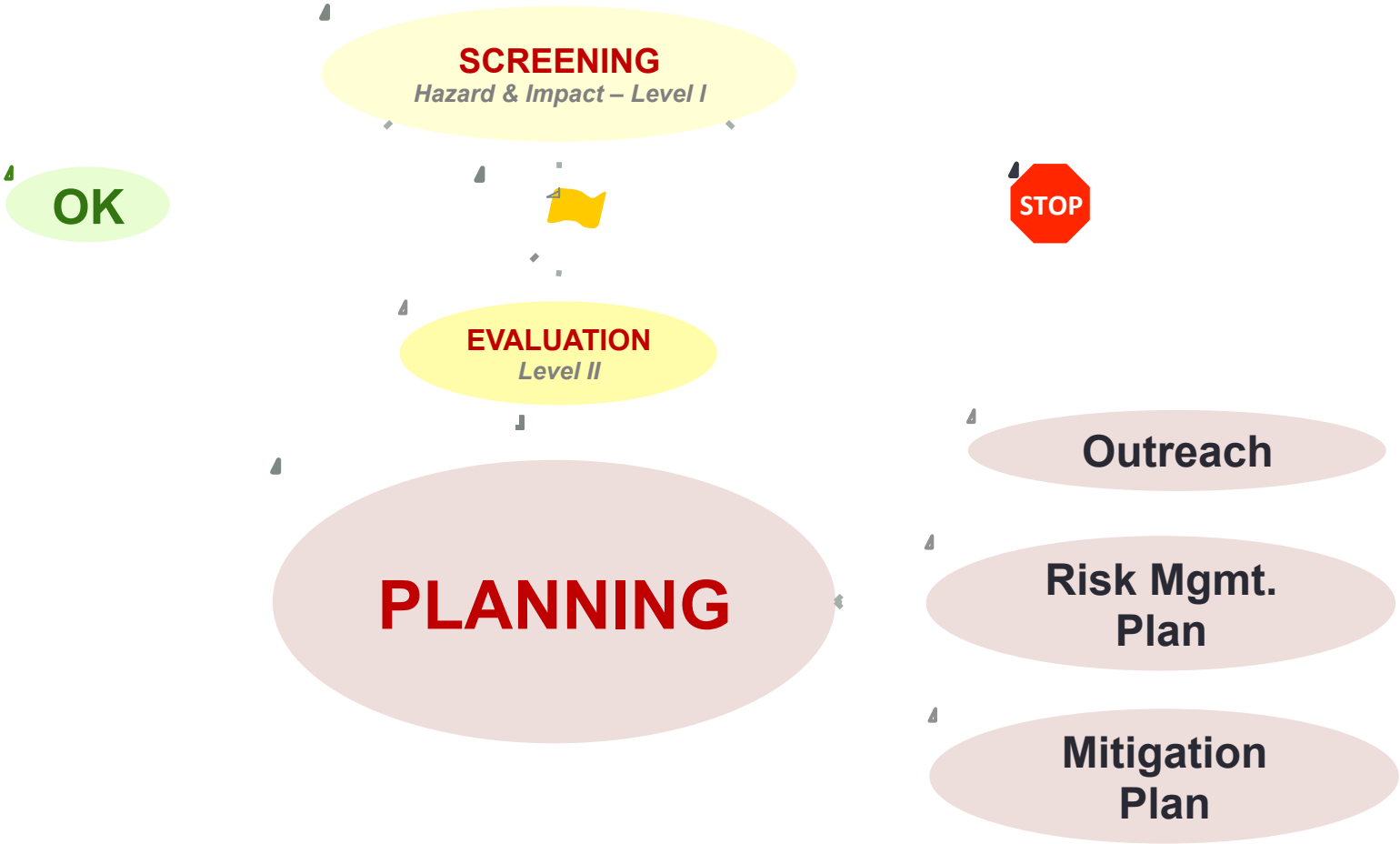
Evaluation – Impact* Evaluation Toolbox

Item	Data, Resources and Tools
Population	Survey 10 mile radius, nearby population centers. Assess the regional population density. Comfort or familiarity with seismic events – assess potential nuisance thresholds
Structures and Infrastructure	Summary of buildings, roads, pipelines, electric grid Critical infrastructure – e.g. Hospitals, schools, historical sites, power plants Construction practices, materials Local codes, seismic event ready?
Dams, Lakes, Reservoirs	Presence of dams, reservoirs. Ages, type of impoundment History of fill/drawdown Substrate – material and known faults
Environmental	General description of local ecology Special environmental hazards, protected species
Intangible	Goodwill, trust, reputation
Risk Assessment	Probabilistic models with both chance of occurrence and estimated ranges of potential outcomes for damage assessments, e.g. from HAZUS (USGS)

**AKA 'Risk'*

Toolbox contains various scalable tools user can select to fit for purpose

Framework for Managing Induced Seismicity



If proceeding with well siting . . .

Planning

- Scalable and fit for purpose for the risk of induced seismicity
- Key elements in plan:

1. Conduct **Outreach** to partners and regulators
2. Establish motion thresholds for **Risk Management Plan** “Traffic Lights”
3. Have a plan in place for **Mitigation** if need arises

Planning - Outreach

- Communications plan – community and agencies

1. Identify local, State, and Federal agencies, and their expectations
2. Know regulatory requirements
3. Notification plan – whom, messages, response
4. Dedicated effort in local community – get early buy-in, build knowledge

Adaptable to local conditions and rules

Planning - Risk Management Plan: Traffic Lights

Green — Continue operations – no seismicity felt at surface (MMI I-III+)*

Amber — Modify operations – seismicity felt at surface (MMI III-IV+)*

Red — Suspend operations – seismicity felt at surface with distress and/ or damage (MMI V+)*

Perceived Shaking	Not Felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
Potential Damage	none	none	none	Very Light	Light	Moderate	Moderate Heavy	Heavy	Very Heavy
Peak Acceleration (%g)	<0.17	0.17 to 1.4	1.4 to 3.9	3.9 to 9.2	9.2 to 18	18 to 34	34 to 65	65 to 124	>124
Peak Velocity (cm/s)	<0.1	0.1 to 1.1	1.1 to 3.4	3.4 to 8.1	8.1 to 16	13 to 31	31 to 60	60 to 116	>116
Magnitude	1 – 2.9	3 – 3.9	4 – 4.4	4.5 – 4.9	5 – 5.4	5.5 – 5.9	6 – 6.4	6.5 – 6.9	7.0+
Modified Mercalli	I	II to III	IV	V	VI	VII	VIII	IX	X+

USGS

Traffic Lights *

* *Established based upon local conditions, demographics and codes*

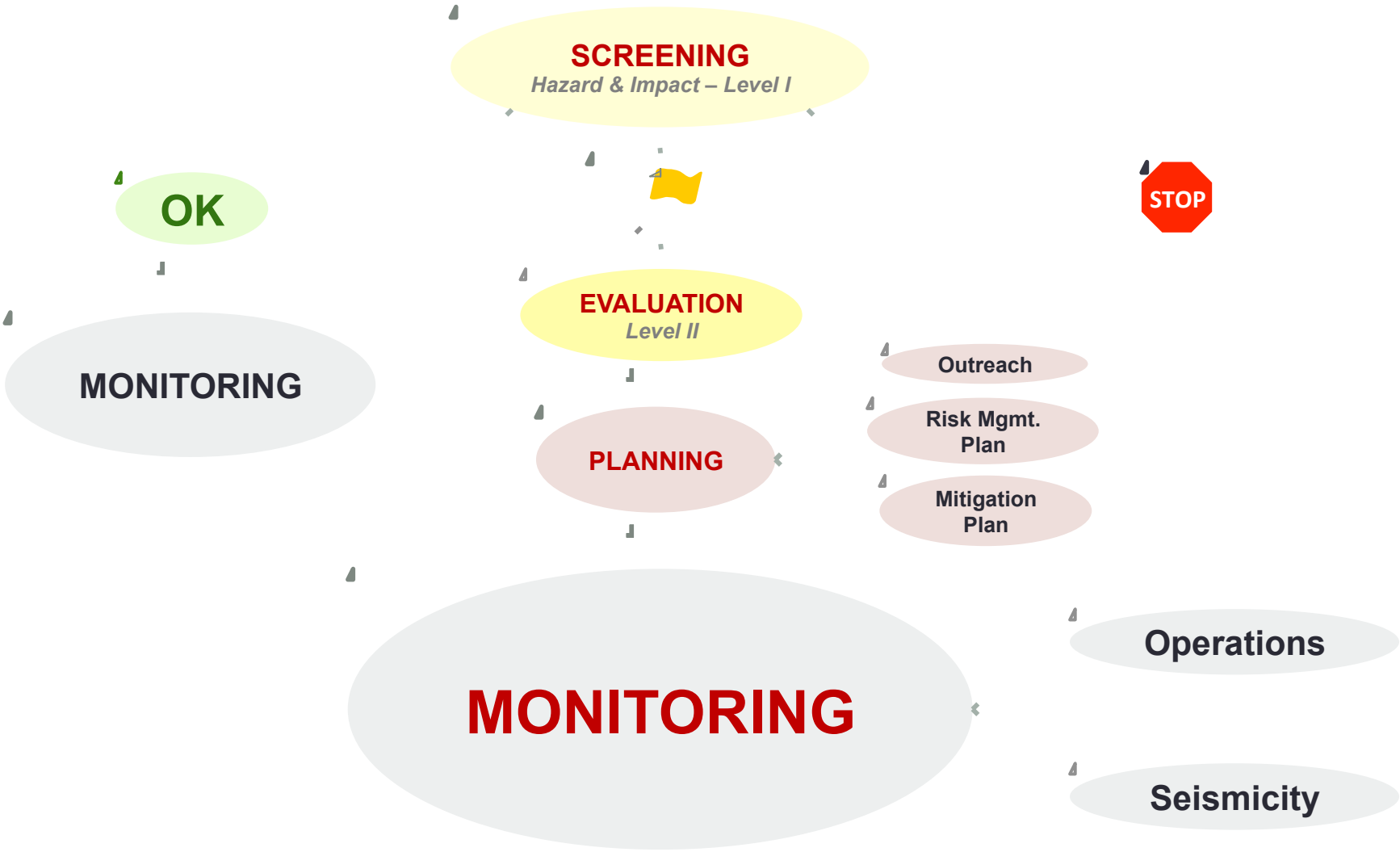
Planning - Mitigation

- Mitigation plan – if and when

1. Steps to measure and calibrate effects
2. Assessment of causes, contributing elements
3. Identify operational levers and possible actions
4. Expanded outreach plan

Adaptable to local conditions and rules

Framework for Managing Induced Seismicity



Pre & Post drilling, or for suspect wells . . .

Monitoring

- Pre-injection
  - BHP, fluids, frac gradient, permeability, stress state
- Operations
  - Injection volume daily, cumulative
  - Injection pressure, average and maximum, increase
  - Reservoir engineering evaluation
- Seismicity
  - Public monitoring
  - Dedicated local monitors

Integrated with Risk Management Plan

- Thresholds for ground motion
- Seismic alerts (e.g. from USGS, local arrays)

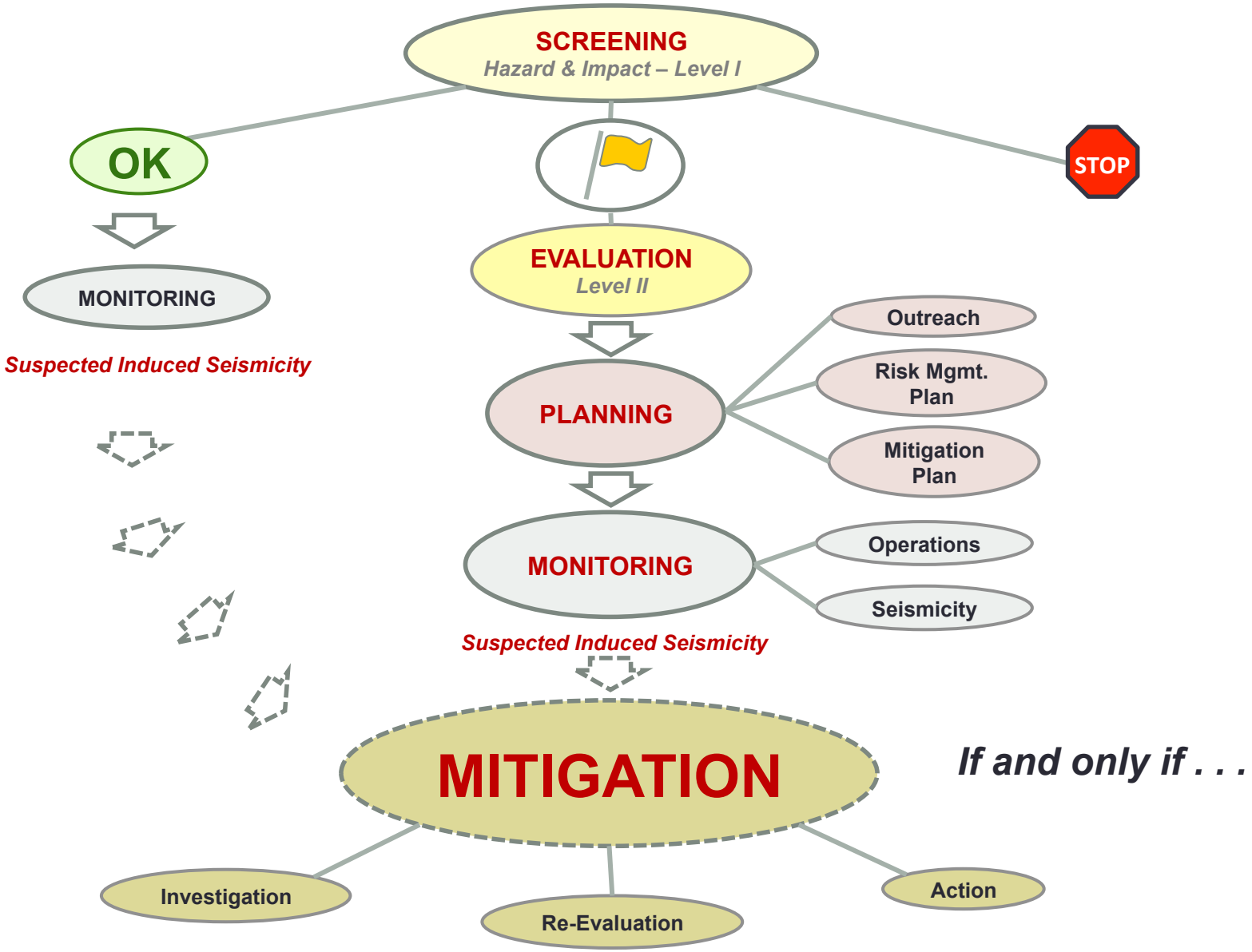
Monitoring – Scalable Toolbox *

- Data, resources and tools for **Monitoring** evaluation

Item		Data, Resources and Tools
Operations	Fluid parameters	• Continuous monitoring and recording of injection rates, and pressures. • Daily and cumulative injection volumes measured and recorded. • Injectant properties noted: e.g. salinity, chemistry.
	Reservoir	• Fluid levels, shut-in pressure, pore pressure, changes in conditions. • Pressure transient behavior – e.g. falloff, step rate tests • Well performance and reservoir flow behavior (Hall plots, Silin plot) Storage/transmissivity
Seismicity	Regional	• Establish baseline conditions from USGS and other regional sources. • Maintain catalog of events from USGS and other regional sources. • Identify excursions from historical trends (temporal and spatial). • Note surface effects from seismic events recorded.
	Local	• (Level II) Install local array sufficient to locate events in the subsurface near the injection zone. • (Level II) Deploy sensors capable of measuring peak ground acceleration and velocity in the vicinity of the injection site. • Monitor possible “traffic light” events within 10 miles of well. • Evaluate whether any observed seismic events are induced or naturally occurring. • Report potentially induced threshold events established in the Risk Management plan that initiate mitigation steps.

** Toolbox contains various scalable tools user can select to fit for purpose*

Framework for Managing Induced Seismicity



If and only if . . .

Risk Mitigation

- **If, and only if**, induced seismicity suspected
- **And** if surface motions exceed thresholds: amber/red traffic light
- Goal is to manage and continue operations safely

Investigation - steps

1. Characterize event – magnitude, location, depth
2. Assess surface effects – motion, impact (distress, damage)
3. Calibrate seismicity to operations
4. Re-visit subsurface data – faults?
5. Improve monitoring

Re-evaluation - steps

1. Refresh evaluation – re-analyze
2. Analyze impact – ground motion studies, damage
3. Perform geomechanical and hydrologic analysis & modeling
   - Fault, stress, connection route of fluids
   - Pore pressure analysis
4. Explore all possible causes – e.g. geothermal, meteorological, production, tectonic
5. Catalog findings to inform mitigation actions

Action

1. Take steps defined in Risk Management Plan ("Traffic Lights")
2. Expand data gathering, monitoring, and analysis
3. Implement outreach plan
4. As necessary modify injection parameters

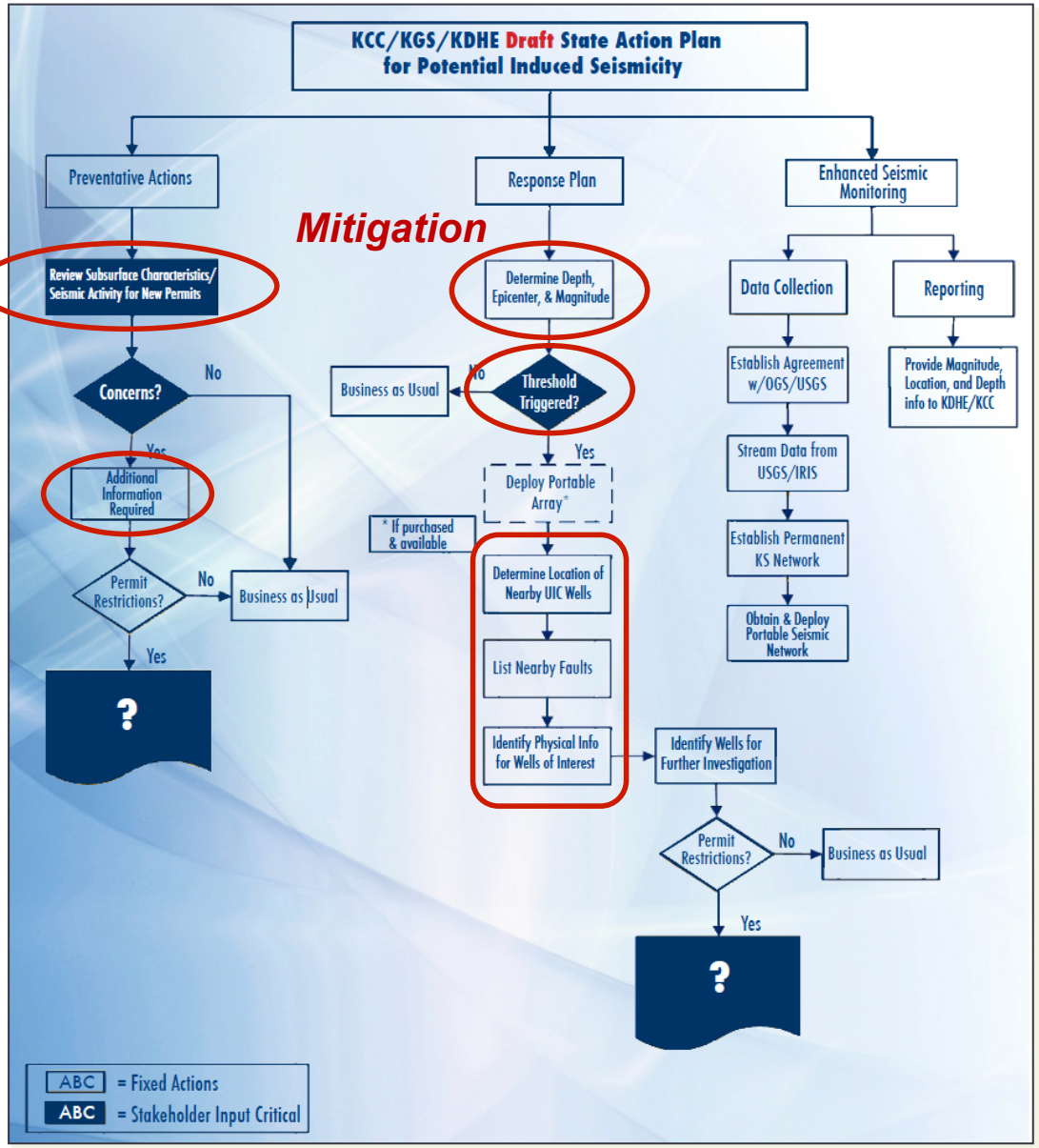
As necessary, utilize evaluation tool boxes

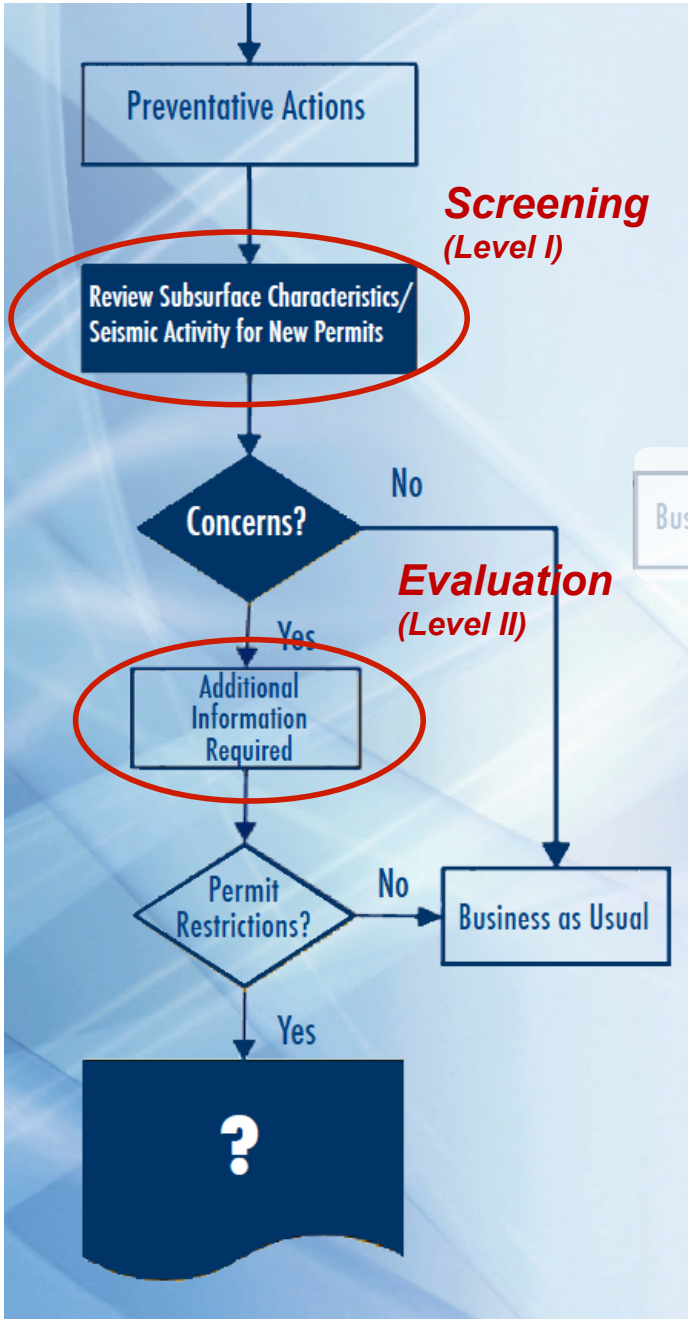
Fit with KCC/KGS/KDHE Draft Plan?

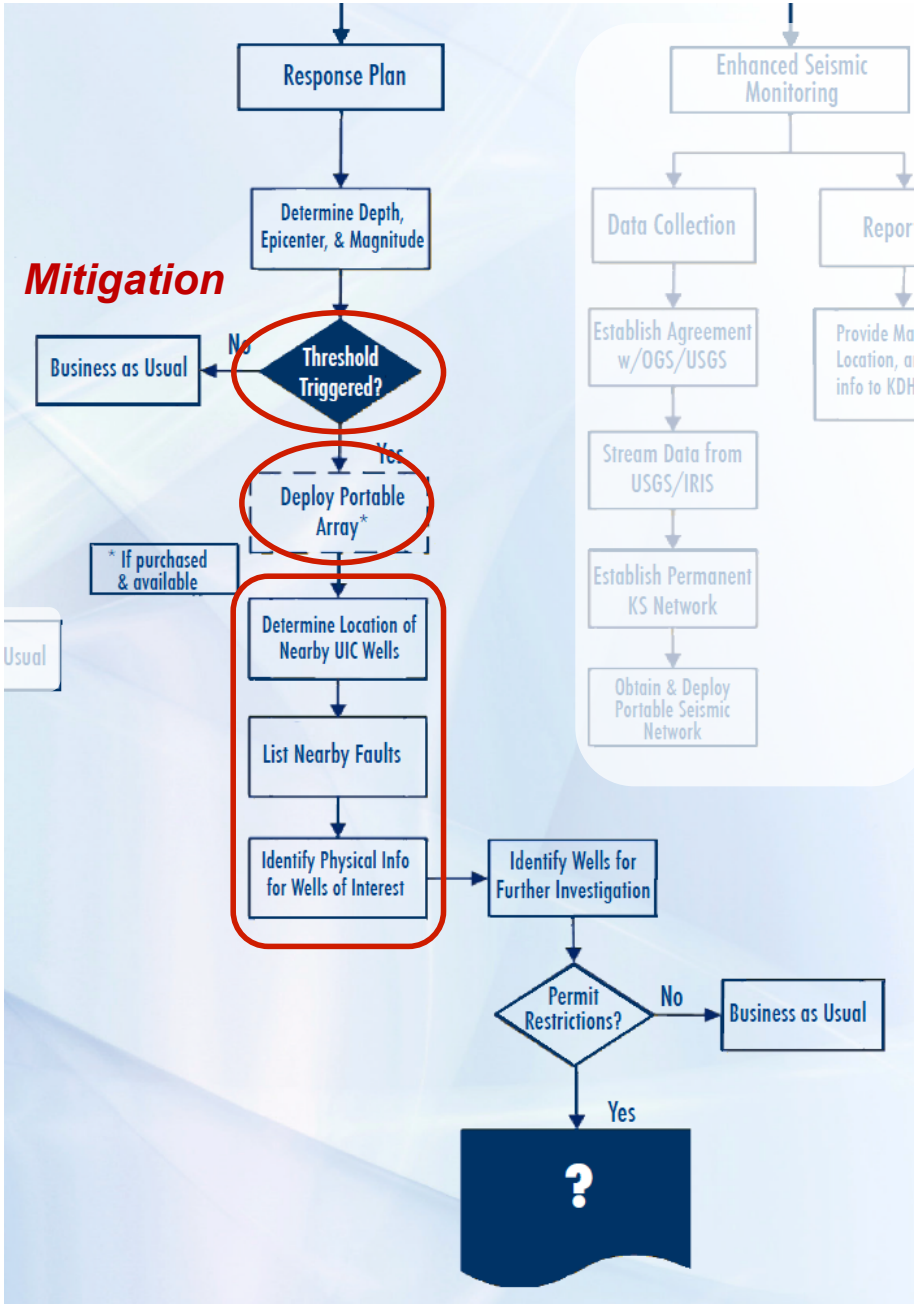
Screening (Level I)

Evaluation (Level II)

Mitigation




Preventative Actions
Screening
(Level I)
Review Subsurface Characteristics/ Seismic Activity for New Permits
Concerns?
No
Evaluation
(Level II)
Yes
Additional Information Required
Permit Restrictions?
No
Business as Usual
Yes
?


Response Plan
Determine Depth, Epicenter, & Magnitude
Mitigation
Business as Usual
No
Threshold Triggered?
Yes
Deploy Portable Array*
* If purchased & available
Determine Location of Nearby UIC Wells
List Nearby Faults
Identify Physical Info for Wells of Interest
Identify Wells for Further Investigation
Permit Restrictions?
No
Business as Usual
Yes
?
Enhanced Seismic Monitoring
Data Collection
Establish Agreement w/OGS/USGS
Stream Data from USGS/IRIS
Establish Permanent KS Network
Obtain & Deploy Portable Seismic Network

OBSERVATIONS

- Induced seismicity risk from hydraulic fracturing is negligible
- Induced seismicity from fluid disposal has occurred in very few, isolated cases
- Appropriate measure of seismicity is local ground motion and its intensity, especially for ‘traffic lights’ plan
- The risk of induced seismicity from fluid disposal can be managed within a fit-for-purpose framework

SUMMARY

- Most situations settled by Screening
  - 

  - 5 Screening Criteria:

    Impact, Basement, Faults, Rate, Seismicity

  - Using available data
- Most disposal wells will be of no concern
- If concern:
  - Evaluate, Plan, Monitor, Mitigate (if)
  - Stop Lights risk management plan with thresholds

WHAT STATES CAN PROVIDE

- Basement surface maps
- Major basement fault maps
- Better seismicity data
- Better disposal data